INVESTIGATION OF ELECTRON IMPACT PROCESSES RELEVANT TO VISIBLE LASERS

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FOREWORD

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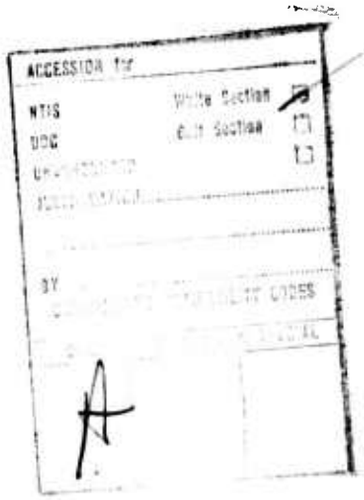

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The program objective is to obtain electron impact cross sections relevant to visible lasers of current interest.

These measurements include excitation of the upper and lower laser levels from the ground state and also excitation from metastable laser levels in order to determine mixing cross sections between the lasing levels.

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Parallel experimental and theoretical efforts are in progress which when combined will yield absolute cross-section magnitudes in the energy range of interest, 0.2 to 20 eV.

The experimental program involves the construction of a crossed electron and atomic beam apparatus. The diagnostic employed is energy analysis of the scattered electrons using an electrostatic analyzer.

The theoretical approach is to develop the mathematical details of a pseudopotential distorted waves theory in a generally applicable form so that it can be applied to the various species of interest.

During this six-month period the program has proceeded according to schedule. Fabrication of the experiment, including vacuum system, electron spectrometer and control circuits is complete, and final assembly prior to testing is imminent. Initial measurements will be performed of known cross sections in He in order to calibrate the system. Thereafter, the metastable state excitation mechanisms and measurement techniques will be initially tested using the noble gases.

The theoretical program, which is a six-month effort, is currently underway.

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I. INTRODUCTION

The motivation for this program was derived from the need for data relevant to modeling high power, visible gas discharge lasers. In particular, data describing the low energy behavior of scattering cross sections in refractory or highly reactive materials is conspicuously absent from the literature, presumably due to the lack of compatibility of these substances with the equipment employed for the measurements. Specific examples of these two classes of species are metal atoms and the halogens.

Where the need for these cross-section data arises, the approach often adopted is to scale the cross sections according to their optical oscillator strengths, however, in the low energy regime of interest several effects can render this a very poor, if not totally inaccurate, procedure. These effects include contributions to the cross sections from resonances or temporary negative ion states, which are know to dominate low-energy electron-atom and electron-molecule scattering[1] and are not related to optical oscillator strengths. Furthermore, the electron impact cross sections for so called forbidden or non-electric dipole transitions certainly do not scale according to their optical oscillator strengths, and, in fact, it is well known that in the threshold region the inverse of the oscillator strength scaling procedure would be a closer approximation.

A category of processes (as distinct from species) which has largely been unexamined to date, due again to technical difficulties related to generation and manipulation, involves electron scattering from excited atomic states. Metastable states of the noble gases which lie close to their ionization continue to play a critical role in determining discharge stability in high power, rare gas halide lasers, such as KrF. Since the importance of excited species in high power lasers is well recognized, the ability to measure certain processes of this type was incorporated into the experimental design. In the case of noble gases, discharge and electron beam excitation schemes will be employed to generate metastable atom species. For refractory species, the excitation scheme will be confined to the electron beam technique.

A number of experimental difficulties complicate the measurement of accurate absolute cross sections, when using the crossed beam technique. This is particularly true in the case of condensable vapors and for most metastable species. Such experiments generally employ normalization techniques using know cross sections in well understood systems, such as helium. However, the technique requires a measurement of the background gas pressure generated by the atomic beam in order to normalize to the known species. This procedure is clearly not applicable to condensable vapors. In the case of metastable species, the difficulty lies in assessing the excited state populations. If secondary emission coefficients are known,

Auger detector techniques may be employed. Currently, however, data on only a very limited number of species are available. This technique is also limited to those metastables which energetically are capable of inducing electron ejection from metals, which implies energies in excess of the work function, typically 4 eV, and therefore severely restricts the applicability of the technique.

In view of these difficulties, the decision was taken to perform a parallel theoretical task which would yield reliable absolute cross-section magnitudes at relatively high energy (>50 eV) and to which the experimental data could be normalized. By confining the theoretical effort to the high energy region, complex resonance interactions could be neglected, thus greatly simplifying the theoretical approach. The proposed theoretical approach involves a pseudopotential distorted waves method, which is novel insofar as application to forbidden transitions is concerned. The proposed program plan is to develop the mathematical details of the theory in a general form so that it can be applied to the various species of interest. The pseudopotential distorted waves theory will be applicable both to excitation and collisional mixing processes in complex atoms.

II. EXPERIMENTAL DESIGN AND CONSTRUCTION

A schematic of the experiment is shown in Figure 1. The experiment employs the crossed-beam technique whereby a low density metal atom beam is collided at right angles with an electron beam of the appropriate energy, and the intensity and energy distribution of the inelastically scattered electrons are measured using a hemispherical electrostatic electron energy analyzer. The electrostatic analyzer is rotatable from -30° to $+145^{\circ}$, thus permitting measurements of the differential cross section to be made at a number of angular locations. When integrated over all angles these data yield the total scattering cross section.

An electron beam generated from a thermionic hot filament electron source is focused and energy controlled by a system of electrostatic lenses. Since only the broad features of the energy dependence of the cross section are of interest, no attempt is made to define the energy spread (resolution) of the electron beam beyond the natural thermal spread obtained from the heated filament, which, combined with the voltage drop along the filament, yields a half width of approximately 0.2 eV, characteristically.

Those electrons which are scattered into the acceptance angle defined by the electrostatic analyzer entrance optics are transported and focused in the entrance plane of the electrostatic analyzer. After transmission and energy selection by the electrostatic analyzer, the electrons are detected by a channeltron multiplier. Pulses from the channeltron will be fed to the input of a unity gain pulse amplifier located immediately on the signal lead vacuum feedthrough. The low output impedance of the pulse amplifier reduces pick-up problems between the channeltron and pulse counting equipment. Standard nuclear pulse counting equipment is employed, which consists of a pulse amplifier and shaper, discriminator, scaler and ratemeter. Since very low count rates are anticipated for the metastable

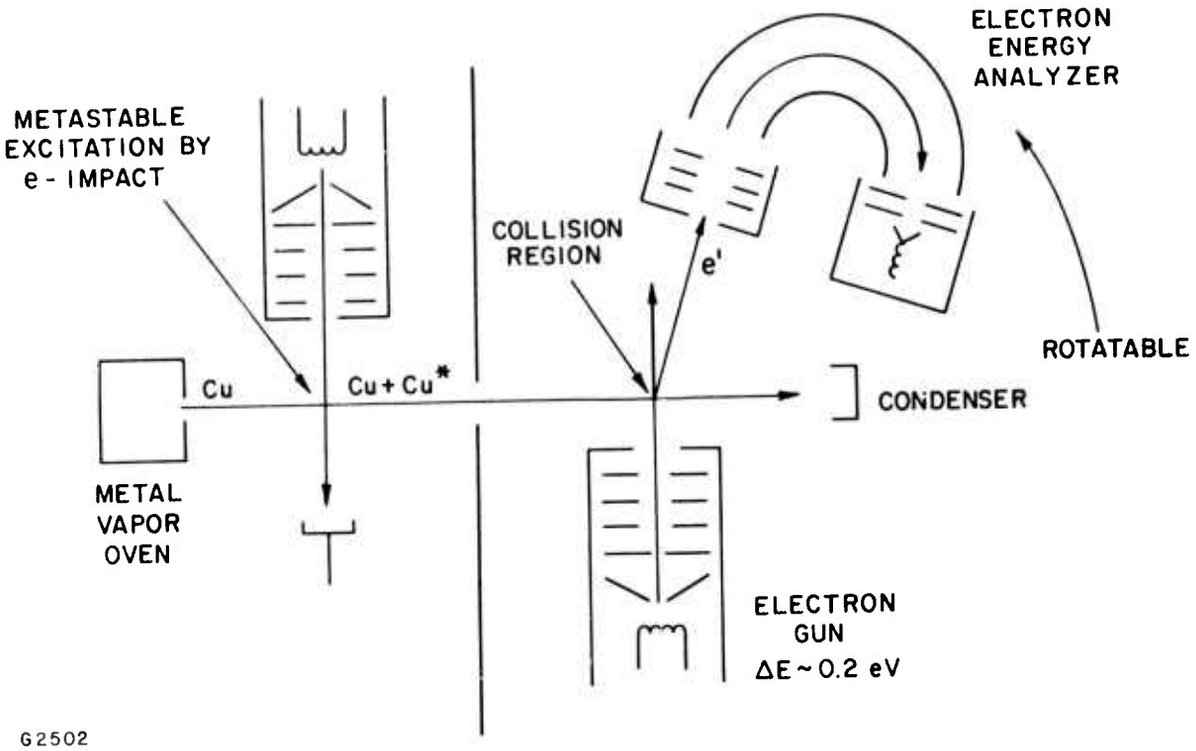

Figure 1 Schematic of Crossed-Beam Apparatus and Electron Beam Metastable Excitation Source

atom measurements, a 10^3 channel signal averager will be employed in order to improve the signal-to-noise statistics by repetitively sweeping the particular electron energy range of interest and storing successive sweeps in the memory of the signal averager.

As mentioned, the objective of the experimental program is to provide relative cross-section measurements whose accuracy is not energy dependent. This requires designing the incident and scattered electron beam optics to possess constant transmission characteristics over the range of energies of interest 0.2 → 20 eV. Both the electron gun and analyzer entrance optics are equipped with three element zoom lenses whose focal properties have been accurately calculated[2] and whose performance has been confirmed experimentally.[3]

Eventually the transmission characteristics of the system will be determined by measuring the elastic scattering cross section in helium. Agreement between experiment and theory has established the accuracy of this cross section to better than 5 percent.[4]

In order to compensate for slight geometrical misalignment and for residual stray electric and magnetic fields, the electron optical train is equipped with four sets of perpendicular pairs of deflector plates to correct for small perturbations to the beam trajectory. The bulk of the laboratory magnetic field is removed by lining the vacuum chamber with magnetic shielding material.

All of the electron optical components, including the hemispherical analyzer, are fabricated from molybdenum, since it is chemically and electrically stable in most environments, which provides for high stability over long operating periods.[5, 6] The various elements are insulated and aligned with respect to each other by 1/16-inch-diam. sapphire spheres, which are highly insulating and provide very small areas for the accumulation of stray electrons which might perturb the beam.

Excitation studies from ground state gaseous species utilize a simple molecular effusion orifice source combined with collimating apertures to yield a well-defined beam. Excitation studies from metastable levels require an initial excitation mechanism in order to generate these species. The energies of the states in question are well beyond the regime accessible to thermal sources and therefore more sophisticated excitation mechanisms must be employed. A variety of possibilities are available: electron beam excitation, discharge excitation, charge exchange processes, or optical pumping mechanisms. For particular systems, a specific mechanism can normally be identified as most suitable. However, in general, the technique of electron impact excitation coupled with electron energy analysis of the scattered electrons has the broadest applicability. This technique has therefore been employed in the present design with the provision of including discharge excitation sources, where applicable, and also the capability of optical detection techniques. The emphasis of the present design is on versatility, since it is anticipated that a wide variety of species and processes will be investigated. Condensable vapors (metal

atoms for example) require a high temperature source. Thus, an electron beam evaporation source, coupled with crossed electron beam excitation for metastable species production, will be employed.

The experiment is enclosed within a double, differentially pumped, stainless steel vacuum chamber, which is bakeable to 200°C and capable of producing an ultimate vacuum in the 10^{-8}-Torr range. A schematic of the vacuum system is shown in Figure 2. The two halves of the vacuum chamber communicate via a small orifice through which the atomic beam passes. Thus the atomic beam source and metastable excitation systems are separated from the electron impact, crossed-beam region and from the electron spectrometer. Each chamber is provided with an automatic gate valve for emergency isolation in the event of power failure and also to provide rapid recycling of the system. Liquid nitrogen traps isolate the oil diffusion pumps to prevent oil backstreaming from the pumps and contaminating sensitive surfaces. Each half of the vacuum chamber is pumped by a 6-inch, high-speed oil diffusion pump.

III. PRESENT STATUS

Design, fabrication and assembly of the pumping system, stainless steel vacuum chamber and gas handling system has been completed. The vacuum integrity of the complete system has been checked and confirmed using a helium leak detector. The vacuum system has been fully instrumented with automatic fail/safe control features. The control circuitry for this instrumentation is also complete. A photograph of the vacuum chamber and pumping system is shown in Figure 3. Figures 4 and 5 are close-ups of the stainless steel vacuum chamber.

Design and fabrication of the electron gun and hemispherical analyzer is complete and final assembly prior to testing is underway. The various control circuits for operating the electron spectrometer have been constructed and tested. The control board is currently being interfaced with the vacuum system electrical feed throughs. Figure 6 is a photograph of the electron spectrometer showing the electron gun (left) and the hemispherical electrostatic analyzer, analyzer entrance optics and channeltron housing (right). The spectrometer is mounted off the 12-inch-diam. Wheeler flange shown in the lower portion of the picture. Figure 7 is a photograph of the electron gun with the outer shield removed. The split plates in the center of the stack are the beam steering plates referred to in the text.

Final cleaning, assembly and electrical connections to the electron spectrometer should be completed in one week. Initially, the operating characteristics of the channeltron multiplier will be measured in order to determine the optimum operating conditions for the pulse-counting circuitry. Testing of the instrument will then commence and the transmission characteristics will be determined from measurements of the elastic scattering cross section in He. Thereafter, the auxiliary electron beam will be installed and measurements of the appropriate ground state and metastable state excitation cross sections will begin.

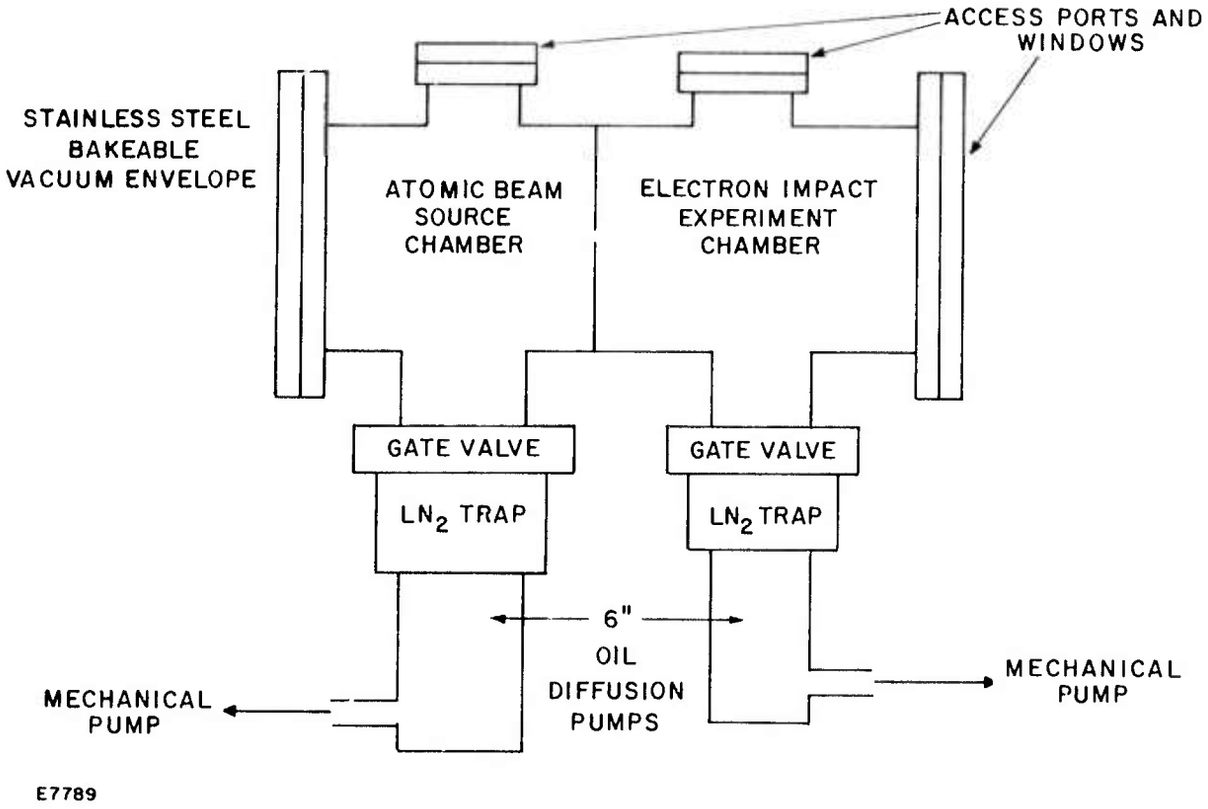

Figure 2 Schematic of Pumping System and Vacuum Chamber

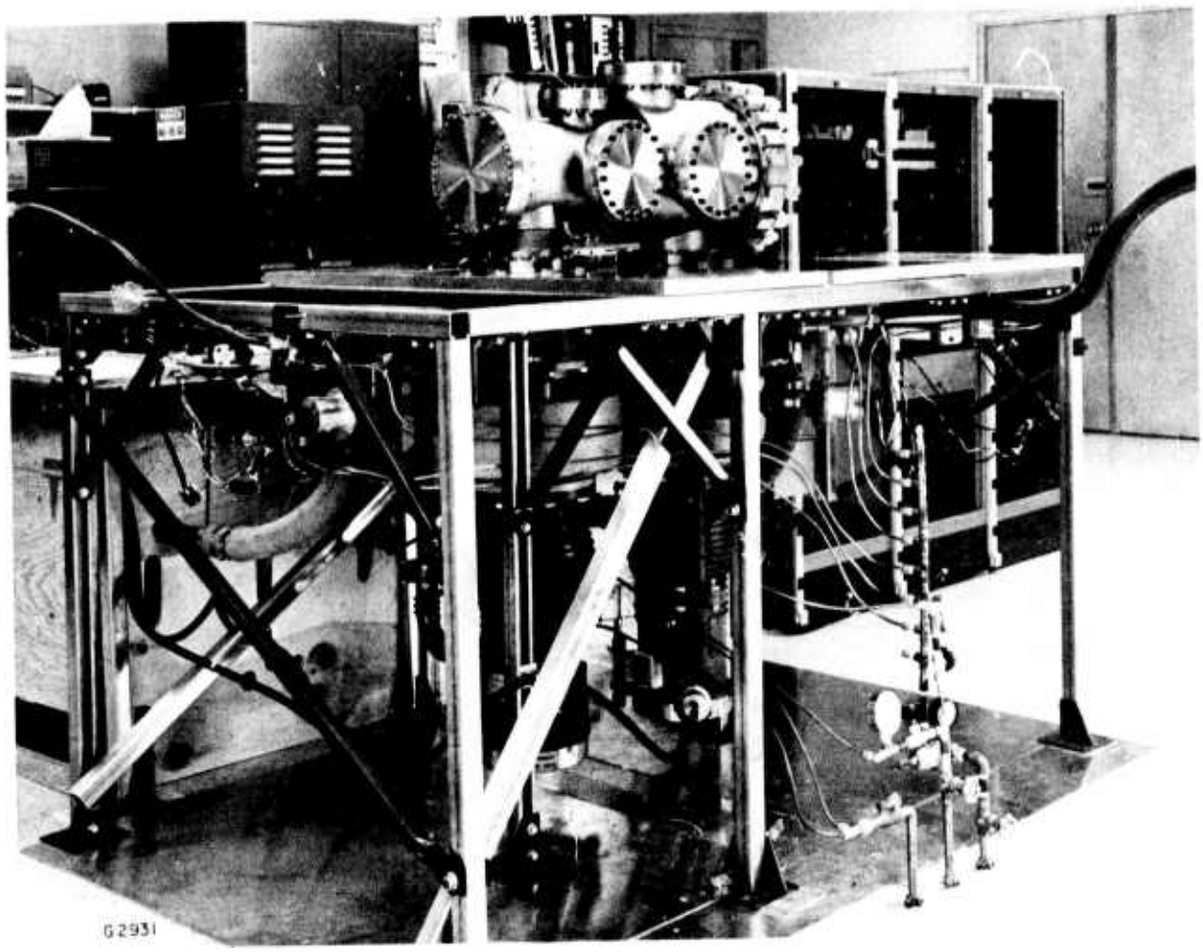

Figure 3 Photograph of Pumping System and Vacuum Chamber

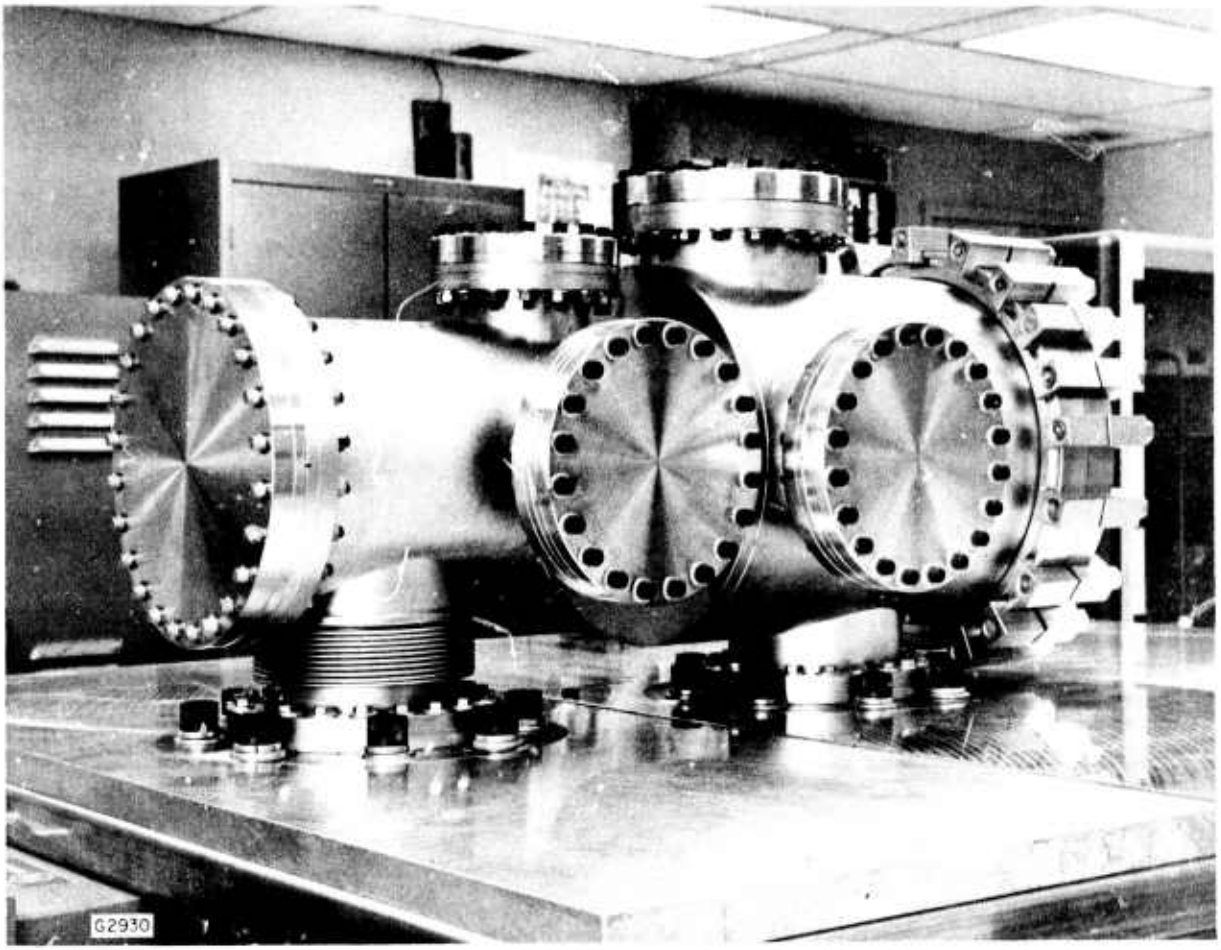

Figure 4 Photograph of Stainless Steel Vacuum Chamber Showing Side Access Ports to Metastable Source and Electron Spectrometer Chamber

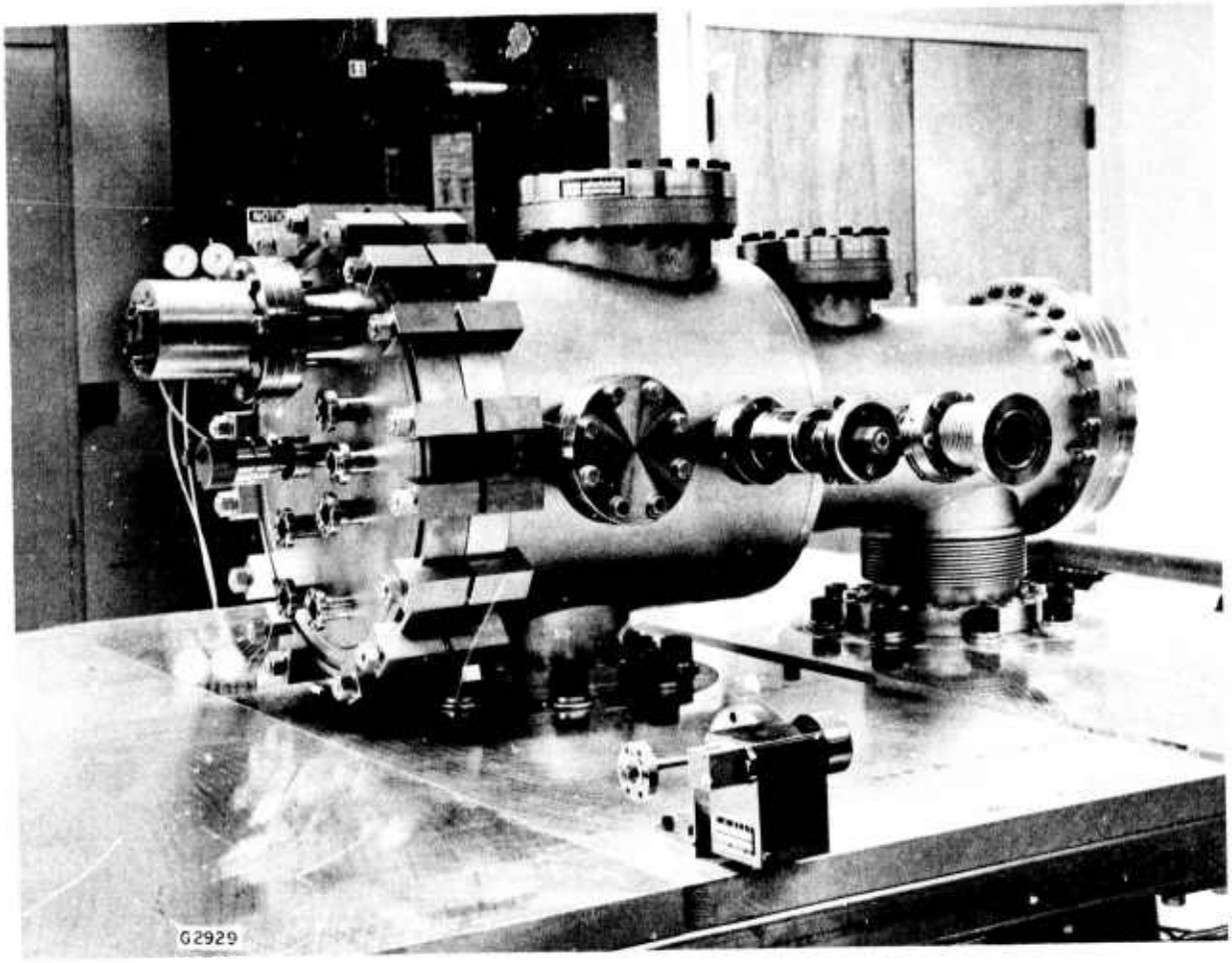

Figure 5 Photograph of Stainless Steel Vacuum Chamber Showing Wheeler Flange and Vacuum Feedthrough

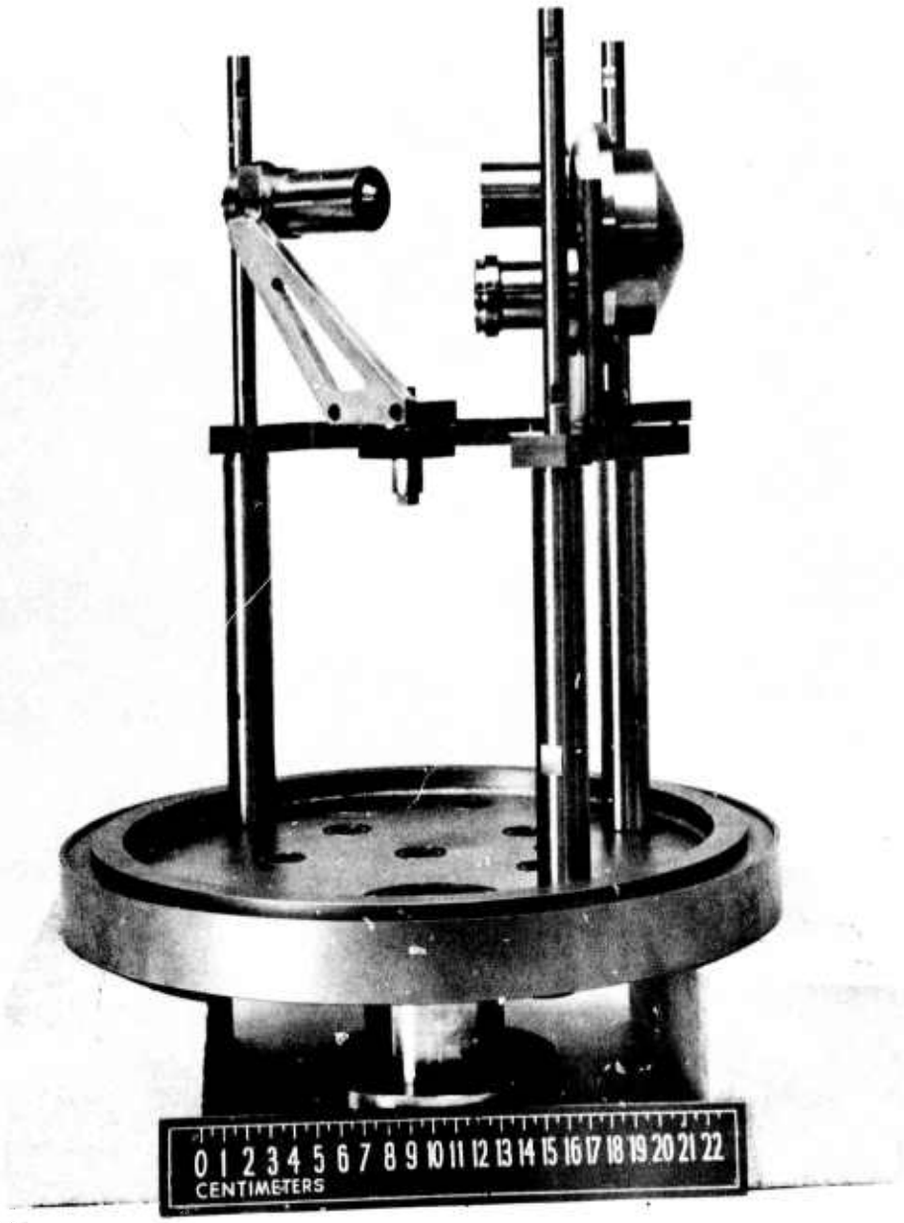

Figure 6 Photograph of Electron Gun and Hemispherical Electrostatic Analyzer Mounted on Wheeler Flange

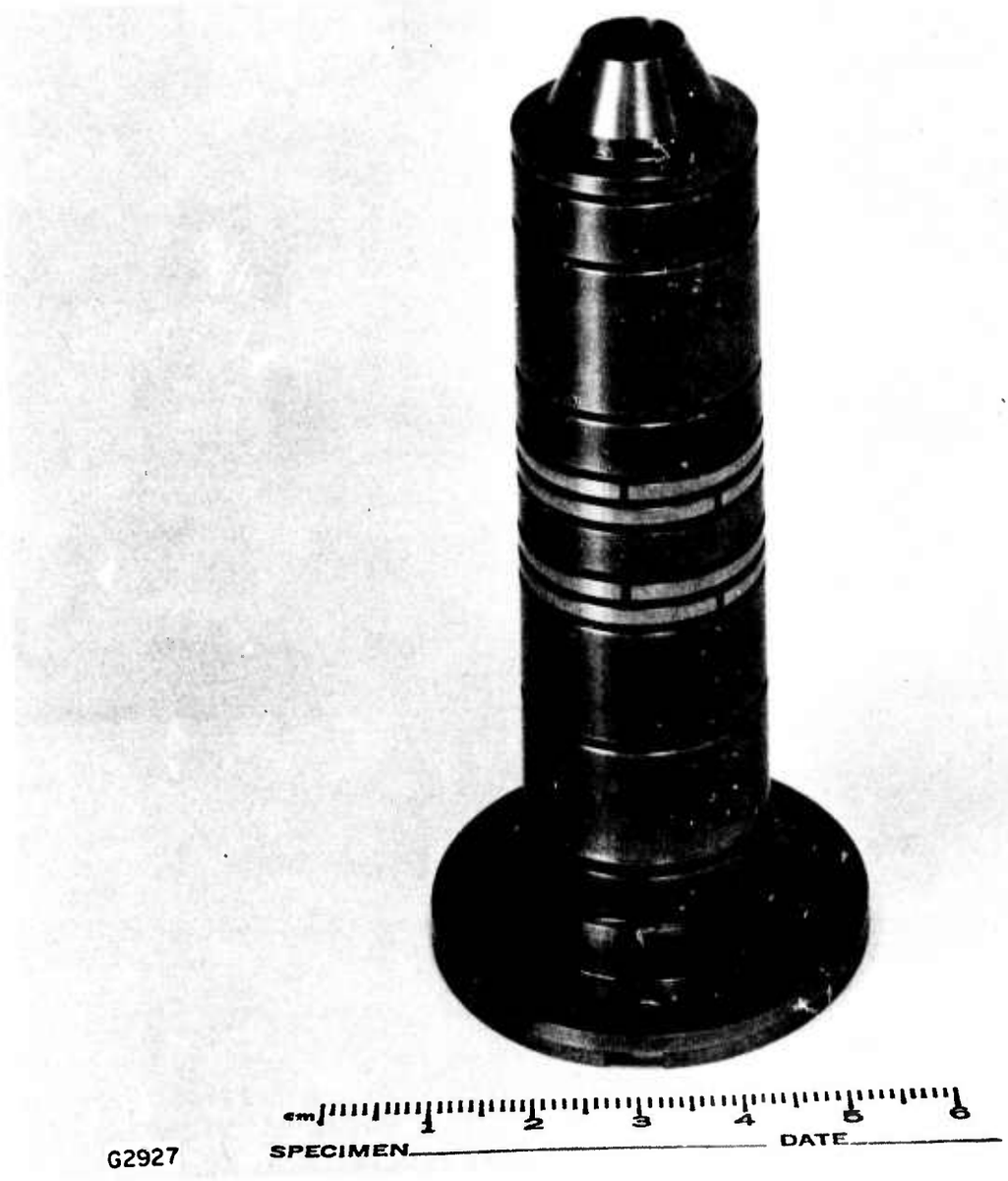

Figure 7 Photograph of Electron Gun with Shield Removed Showing Various Electron Optical Elements

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